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(54) **REVERTING ROUTING DECISIONS MADE BASED ON INCORRECT NETWORK PREDICTIONS**

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H04L 45/302	(2022.01)
H04L 43/08	(2022.01)
H04L 45/30	(2022.01)

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(58) **Field of Classification Search**

None

See application file for complete search history.

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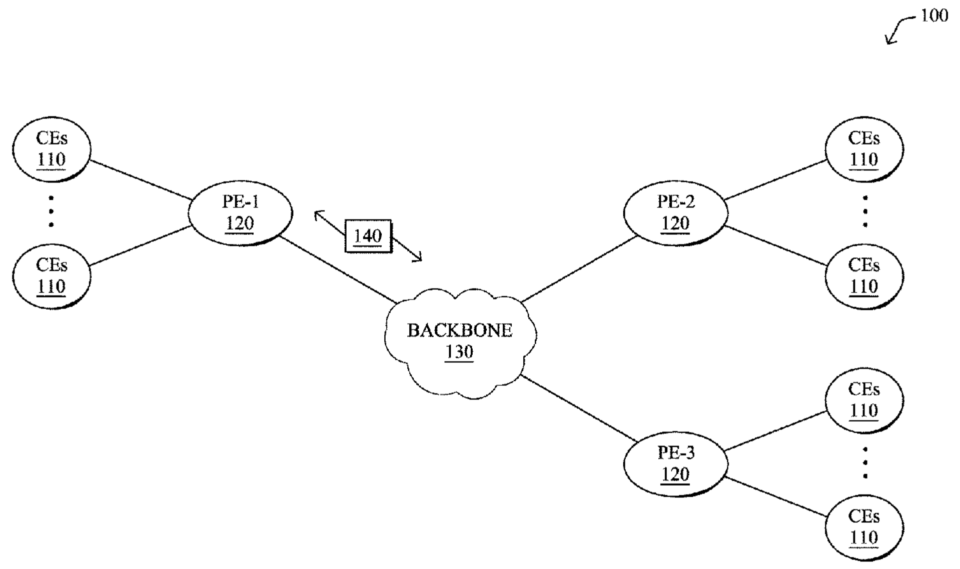
(57) **ABSTRACT**

In one embodiment, a networking device reroutes traffic in a network from a first path to a second path, based on a prediction that the first path will not satisfy a service level agreement associated with the traffic. The networking device enters a fast monitoring state during which the networking device performs fast probing of the first path and of the second path onto which the traffic was rerouted. The networking device makes, based on the fast probing, a determination as to whether the first path would have violated the service level agreement and whether the second path violates the service level agreement. The networking device enacts a routing decision for the traffic by applying a routing policy to the determination.

20 Claims, 13 Drawing Sheets



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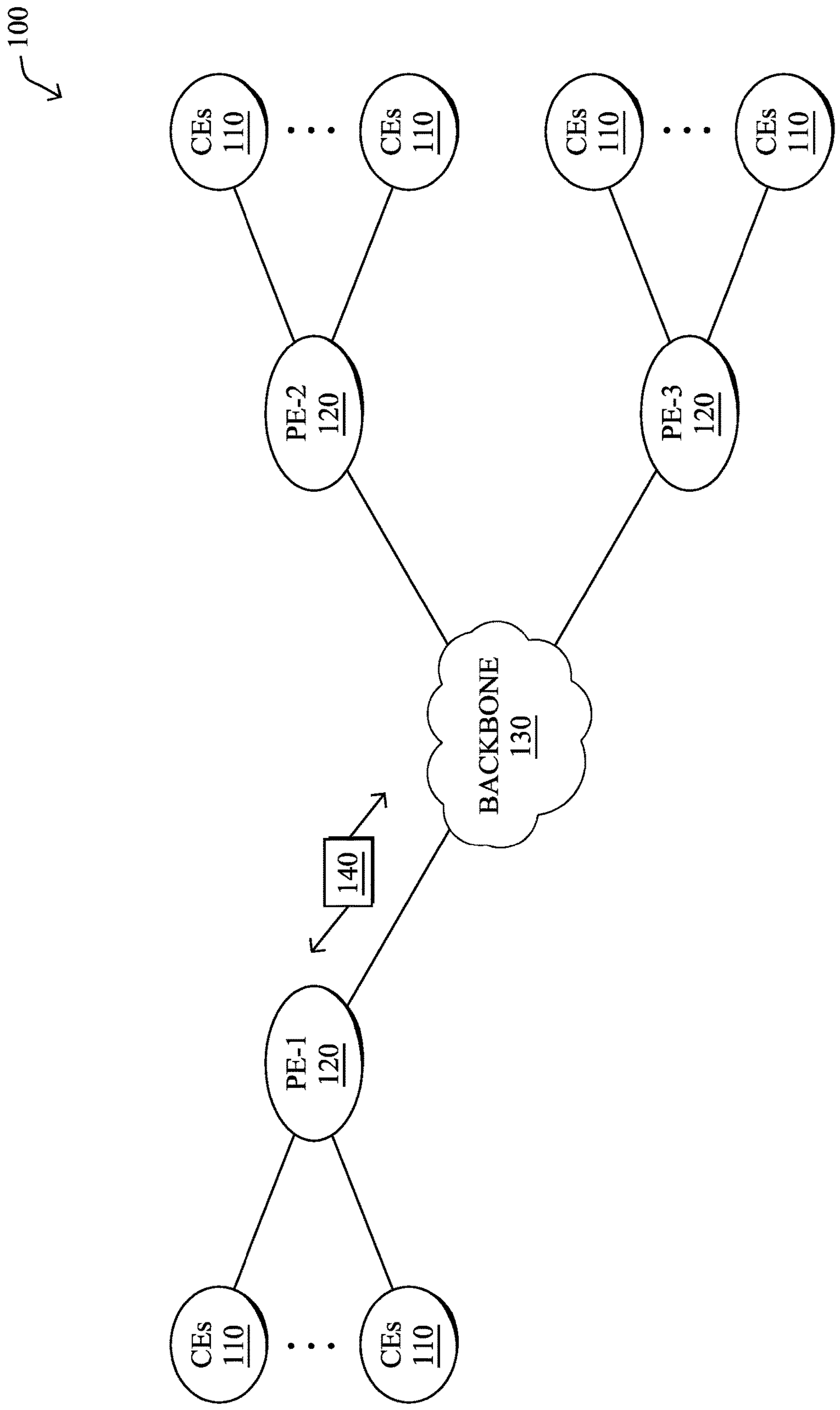
100
CEs 110
CEs 110
CEs 110
CEs 110
CEs 110
CEs 110
PE-1 120
PE-2 120
PE-3 120
BACKBONE 130
140

FIG. 1A

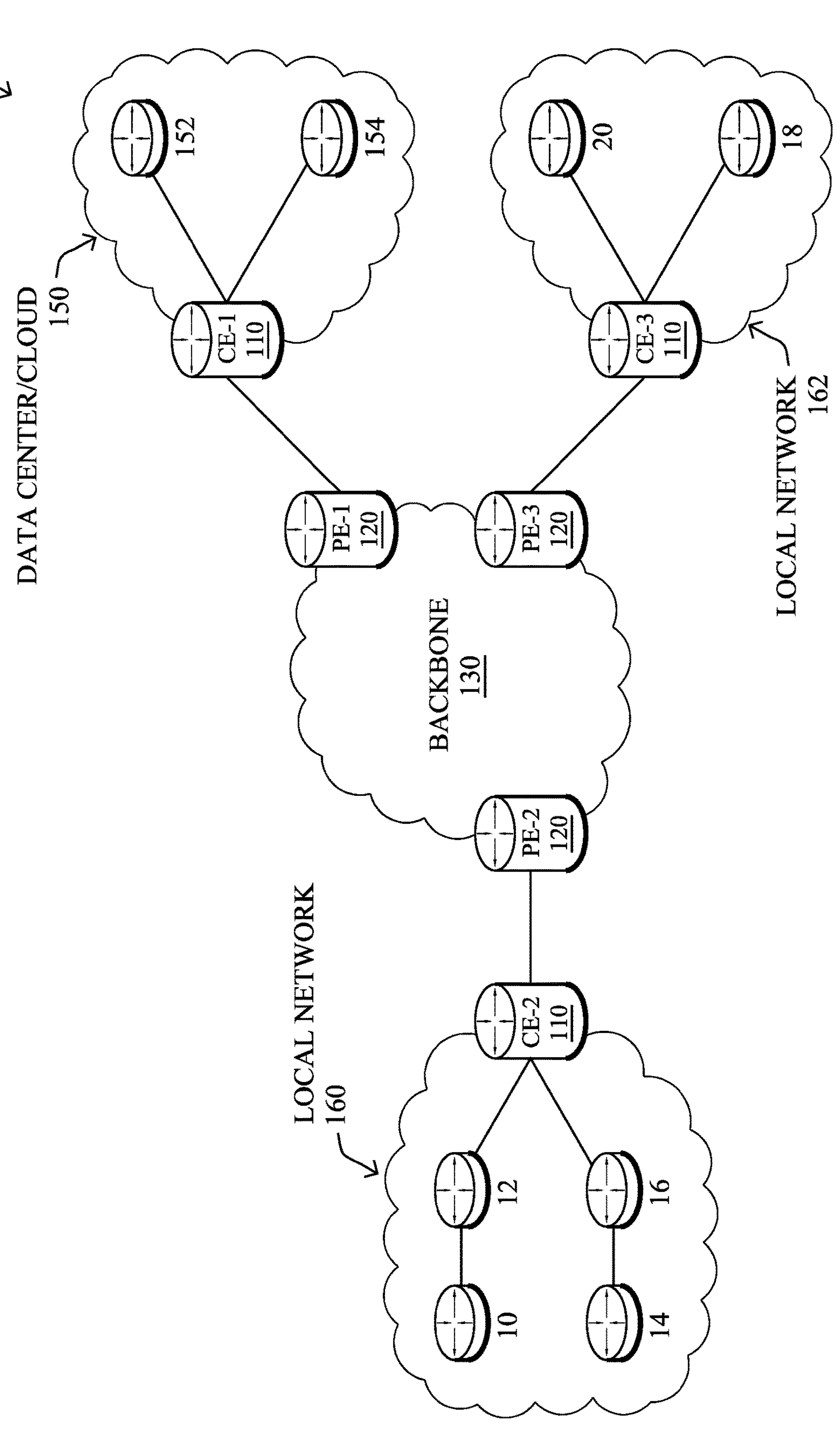
100
DATA CENTER/CLOUD
150
152
154
CE-1
110
PE-1
120
PE-3
120
CE-3
110
20
18
LOCAL NETWORK
162
BACKBONE
130
PE-2
120
CE-2
110
LOCAL NETWORK
160
12
16
10
14

FIG. 1B

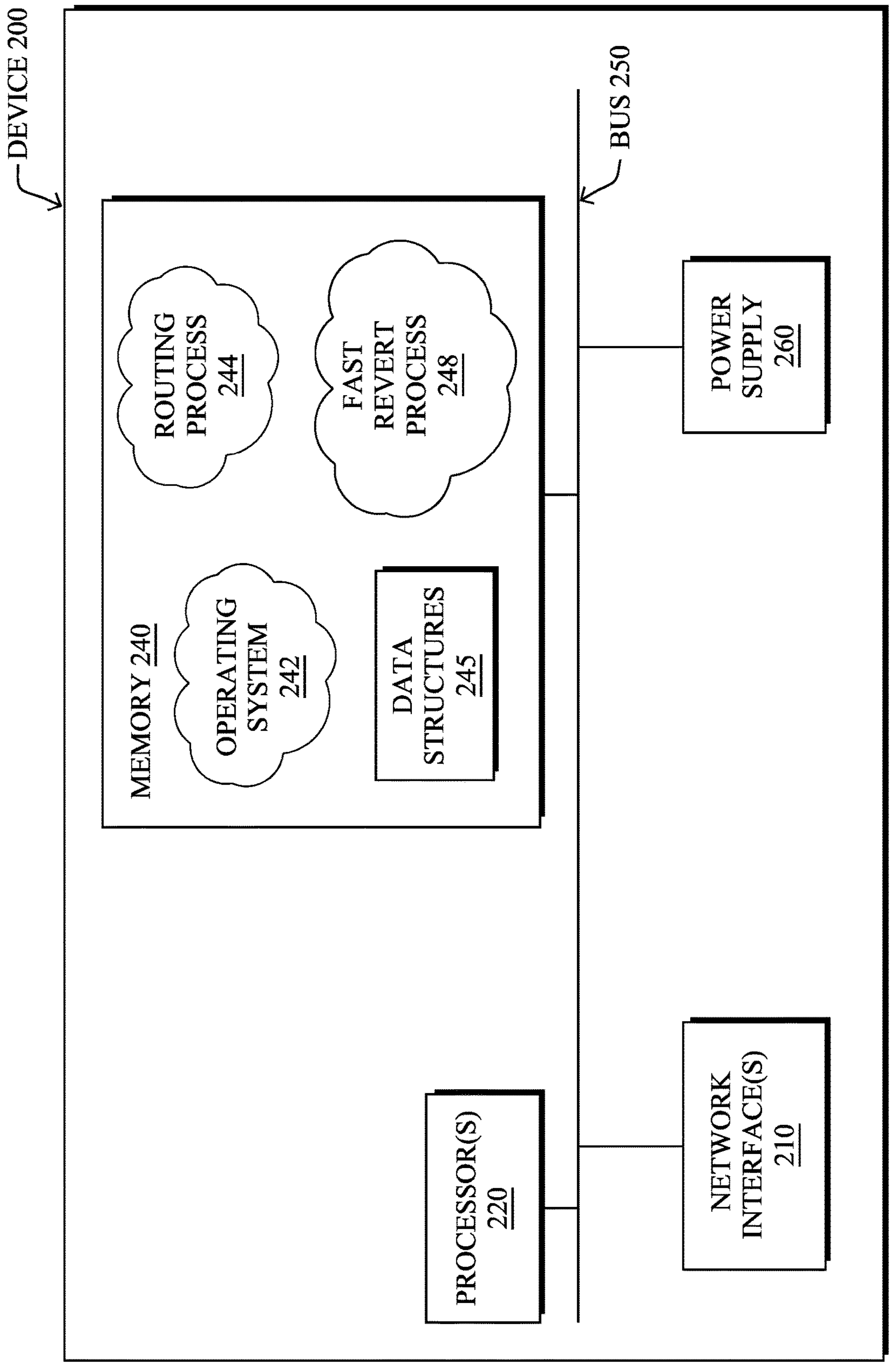
DEVICE 200
BUS 250
MEMORY 240
ROUTING PROCESS 244
FAST REVERT PROCESS 248
OPERATING SYSTEM 242
DATA STRUCTURES 245
POWER SUPPLY 260
PROCESSOR(S) 220
NETWORK INTERFACE(S) 210

FIG. 2

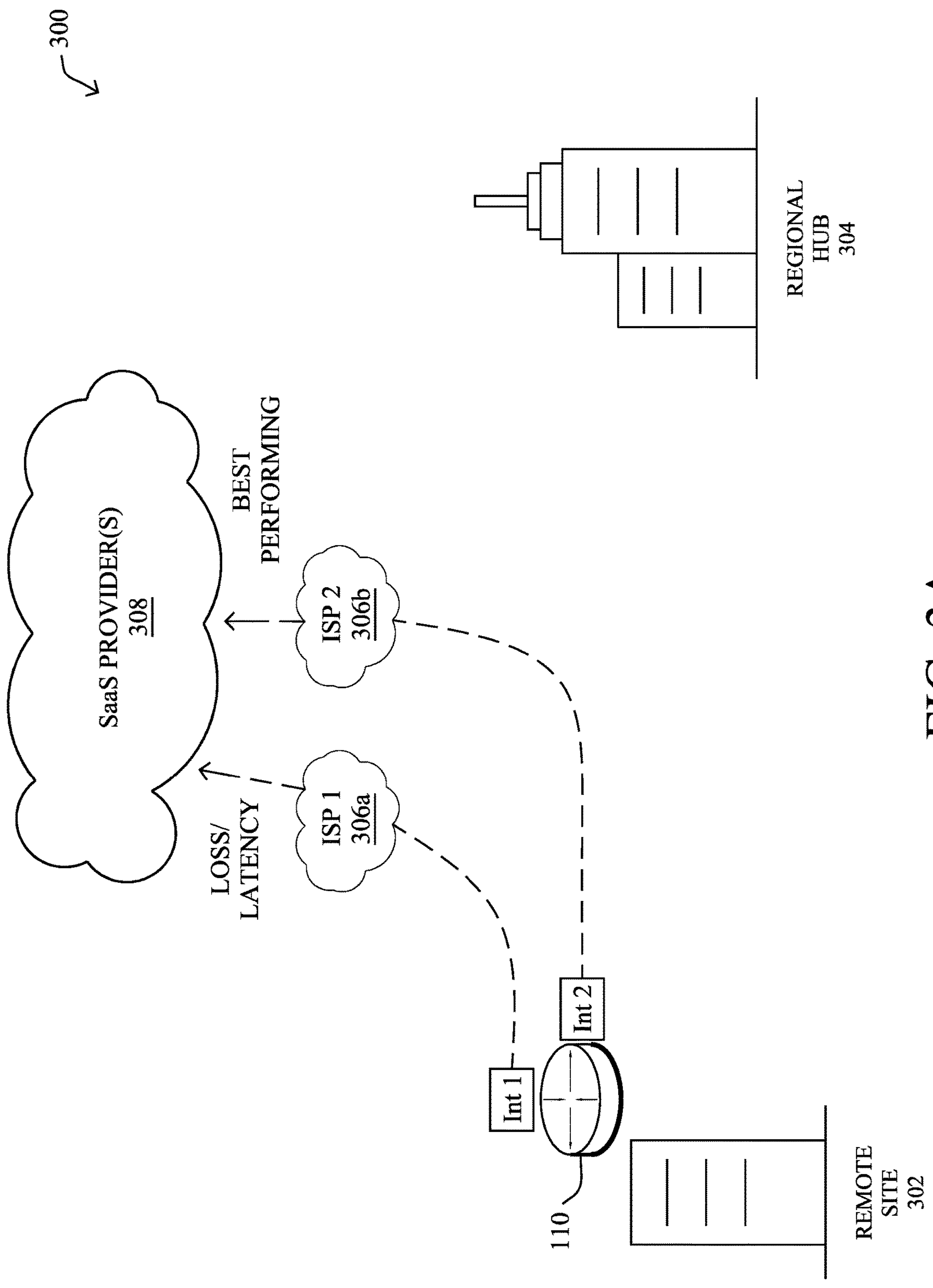
300
SaaS PROVIDER(S) 308
ISP 1 306a
ISP 2 306b
LOSS/ LATENCY
BEST PERFORMING
Int 1
Int 2
110
REMOTE SITE 302
REGIONAL HUB 304

FIG. 3A

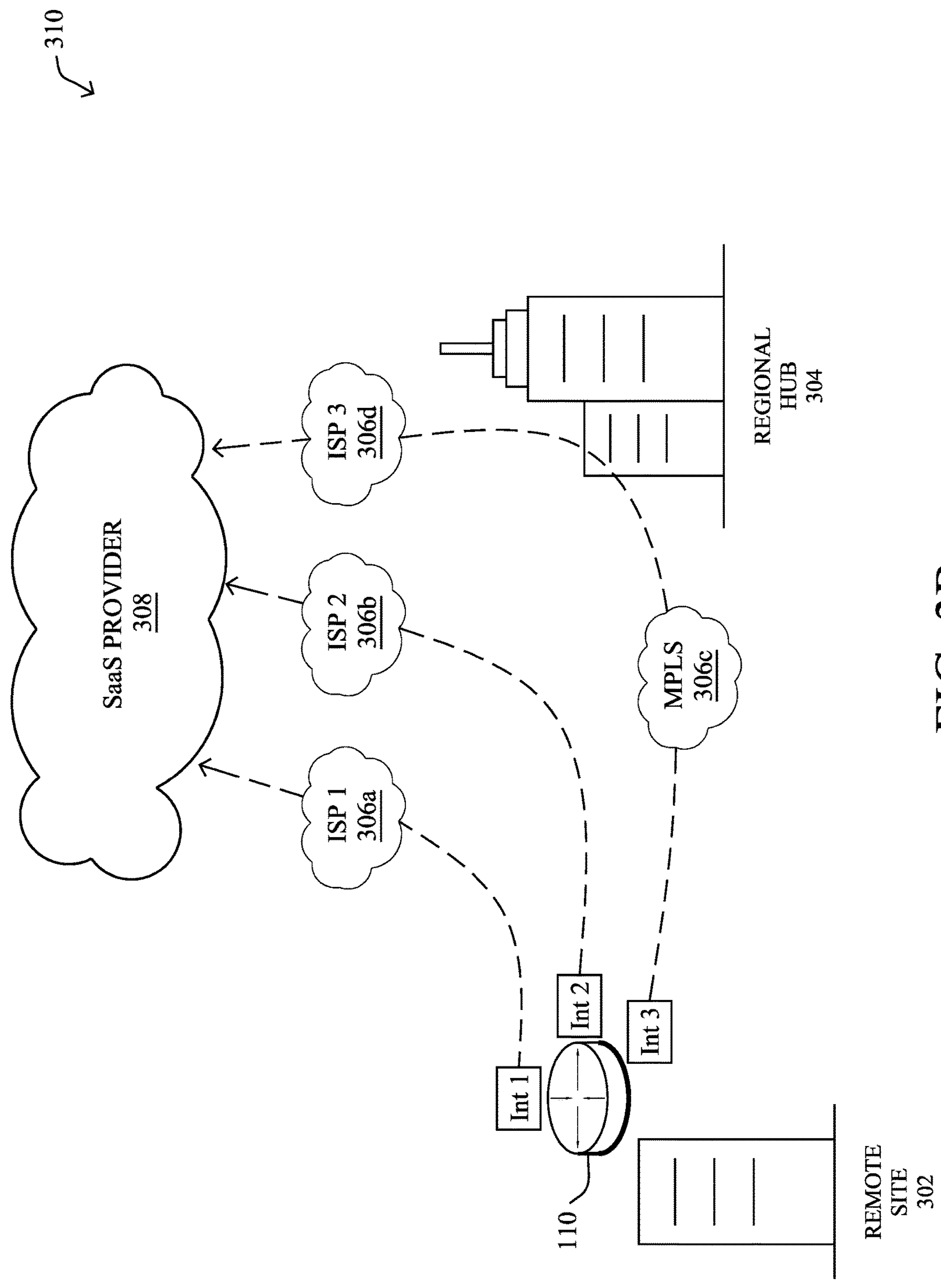
310
SaaS PROVIDER 308
ISP 1 306a
ISP 2 306b
ISP 3 306d
MPLS 306c
REGIONAL HUB 304
Int 1
Int 2
Int 3
110
REMOTE SITE 302

FIG. 3B

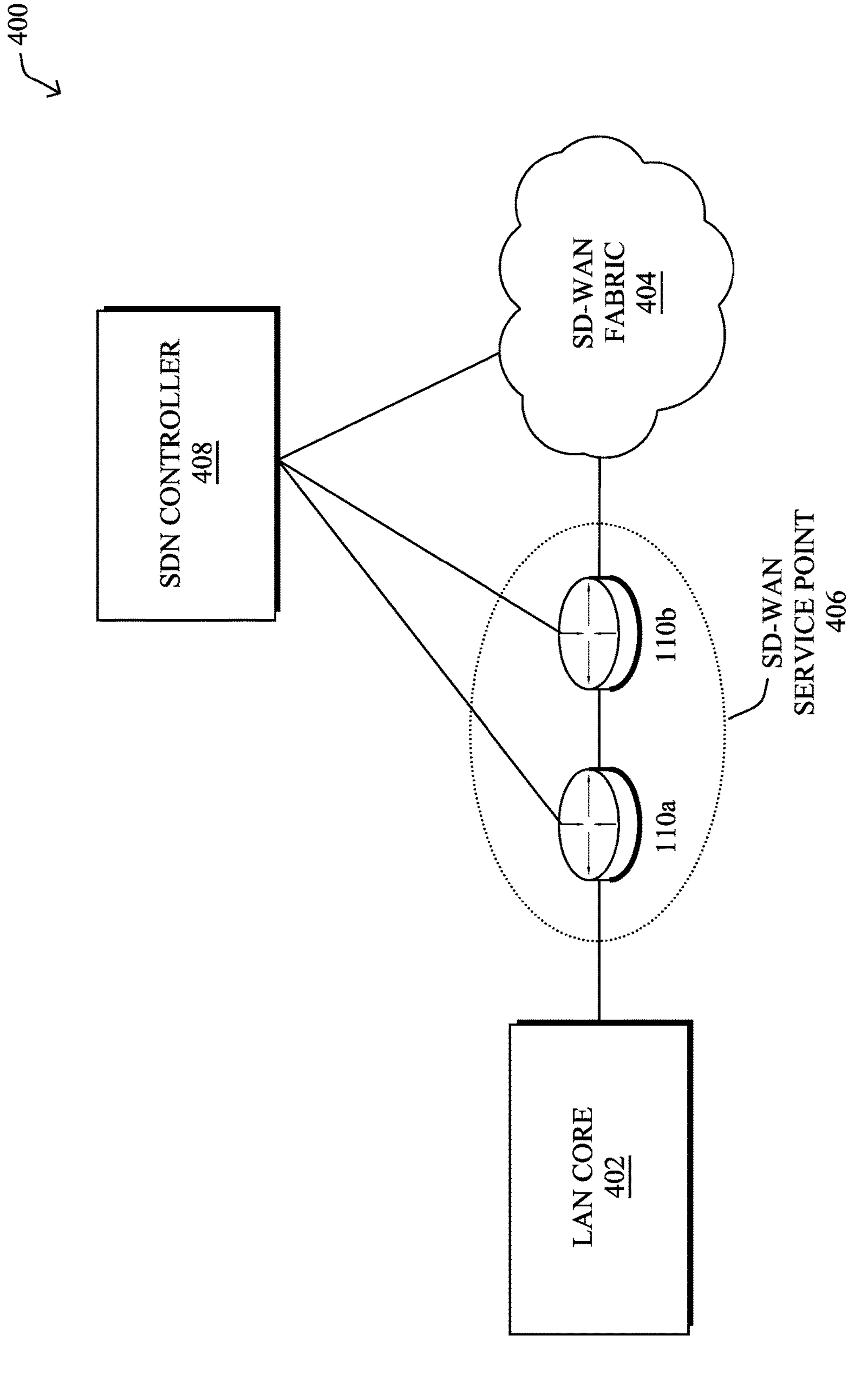
400
SDN CONTROLLER 408
SD-WAN FABRIC 404
110b
110a
SD-WAN SERVICE POINT 406
LAN CORE 402

FIG. 4A

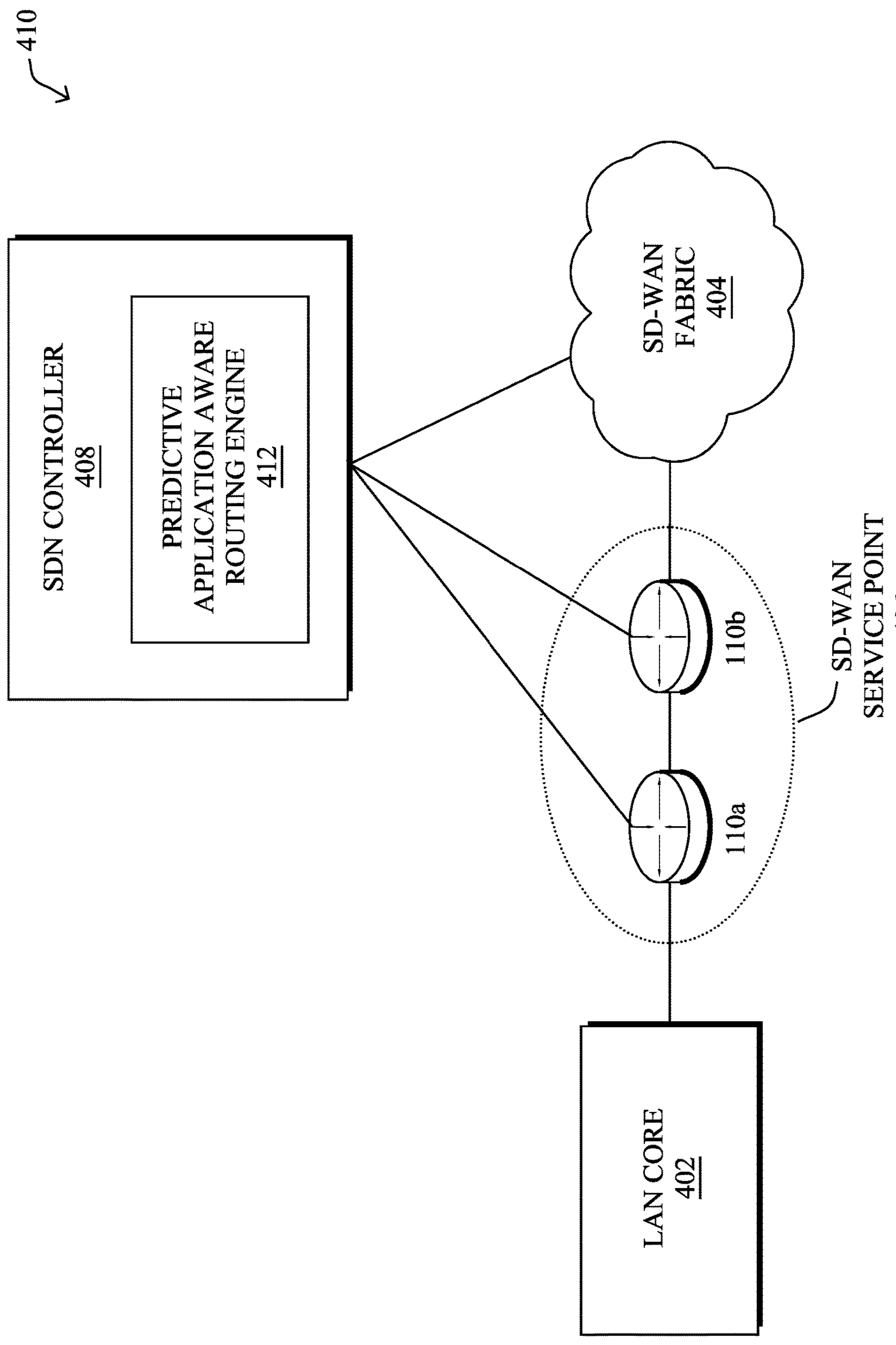
410
SDN CONTROLLER 408
PREDICTIVE APPLICATION AWARE ROUTING ENGINE 412
SD-WAN FABRIC 404
110b
110a
SD-WAN SERVICE POINT 406
LAN CORE 402

FIG. 4B

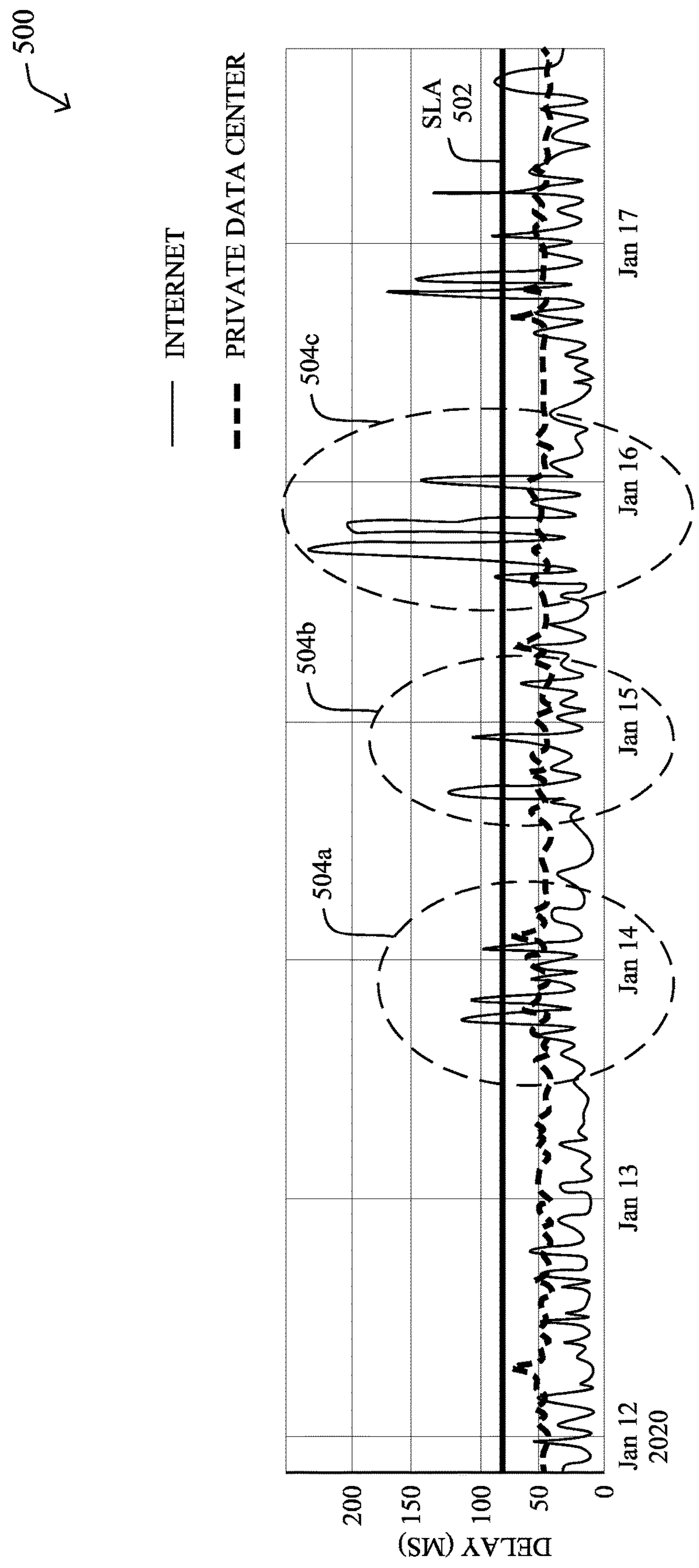
500
INTERNET
PRIVATE DATA CENTER
SLA
502
504a
504b
504c
DELAY (MS)
200
150
100
50
0
Jan 12
2020
Jan 13
Jan 14
Jan 15
Jan 16
Jan 17

FIG. 5

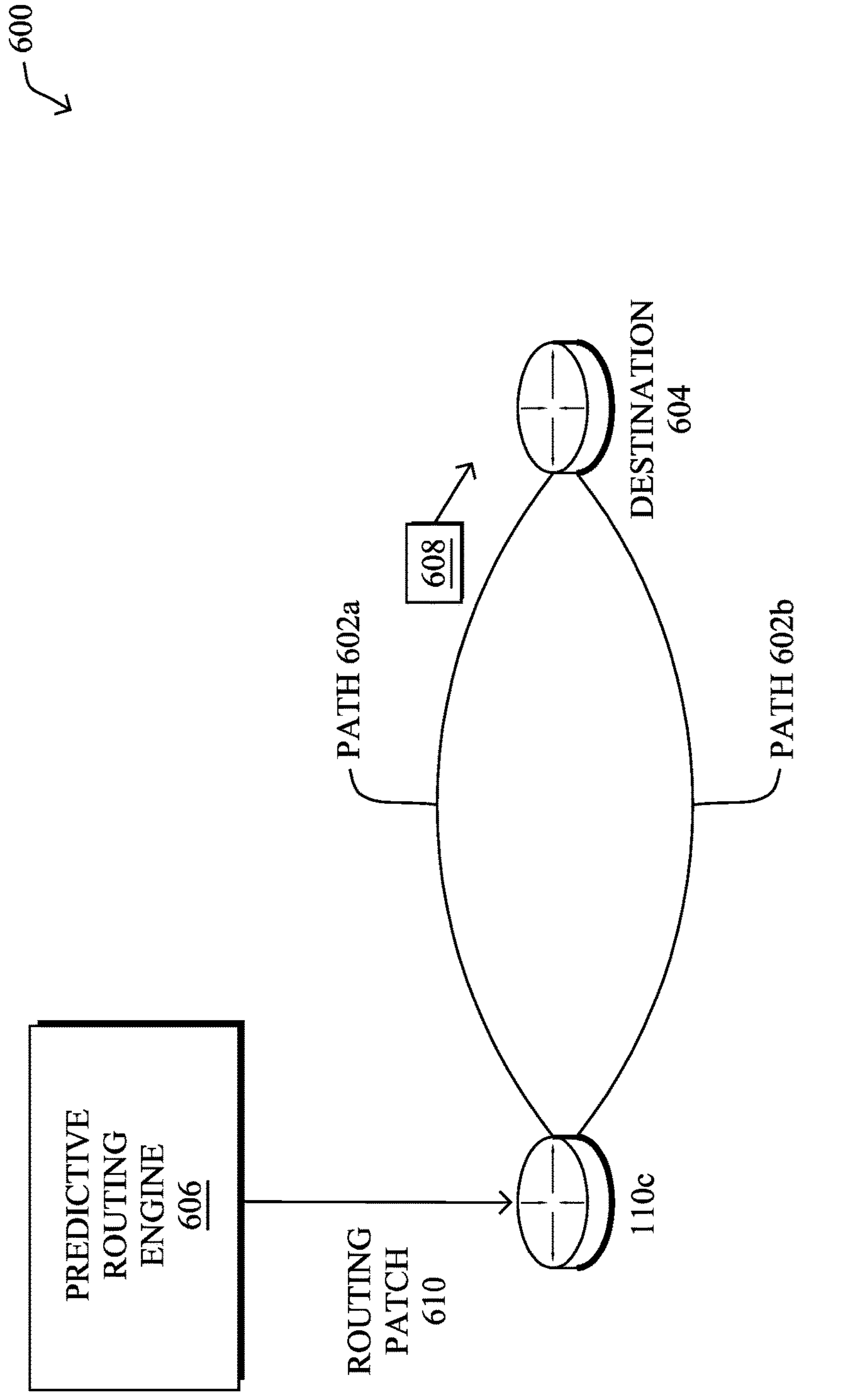
600
PREDICTIVE ROUTING ENGINE 606
ROUTING PATCH 610
110c
PATH 602a
PATH 602b
608
DESTINATION 604

FIG. 6A

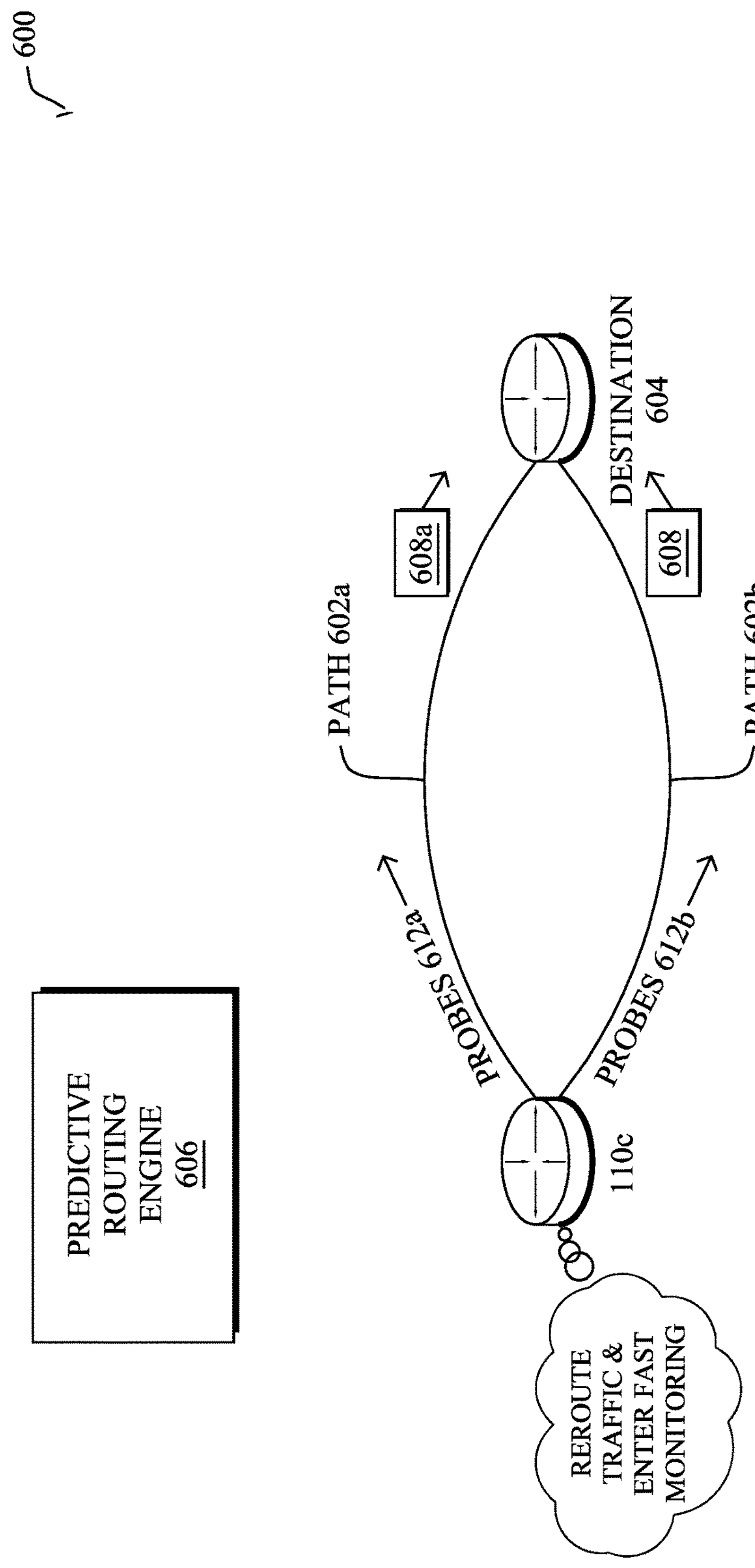
600
PREDICTIVE ROUTING ENGINE 606
REROUTE TRAFFIC & ENTER FAST MONITORING
110c
PROBES 612a
PROBES 612b
PATH 602a
PATH 602b
608a
608
DESTINATION 604

FIG. 6B

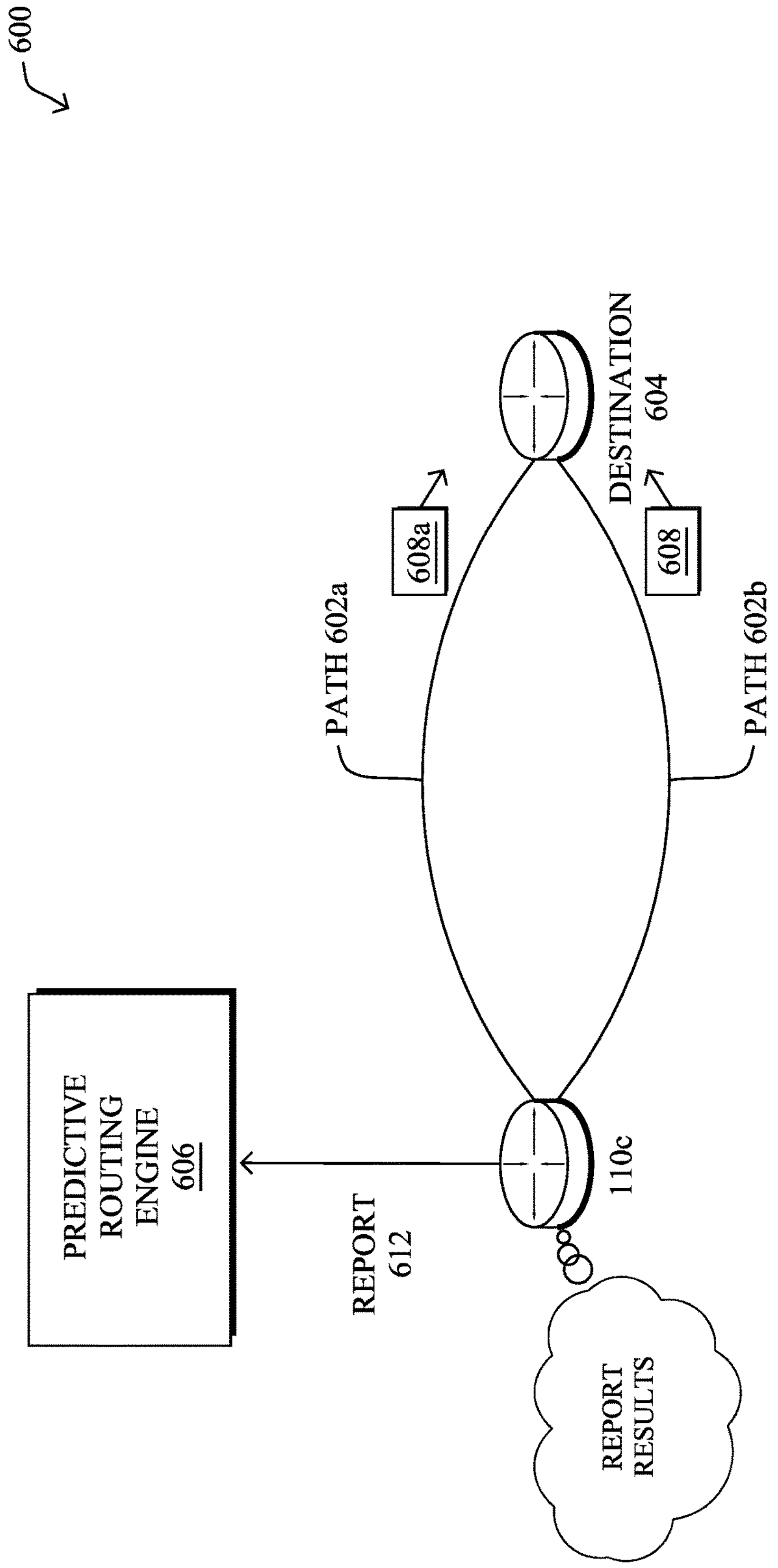
600
PREDICTIVE ROUTING ENGINE 606
REPORT 612
110c
REPORT RESULTS
PATH 602a
PATH 602b
608a
608
DESTINATION 604

FIG. 6C

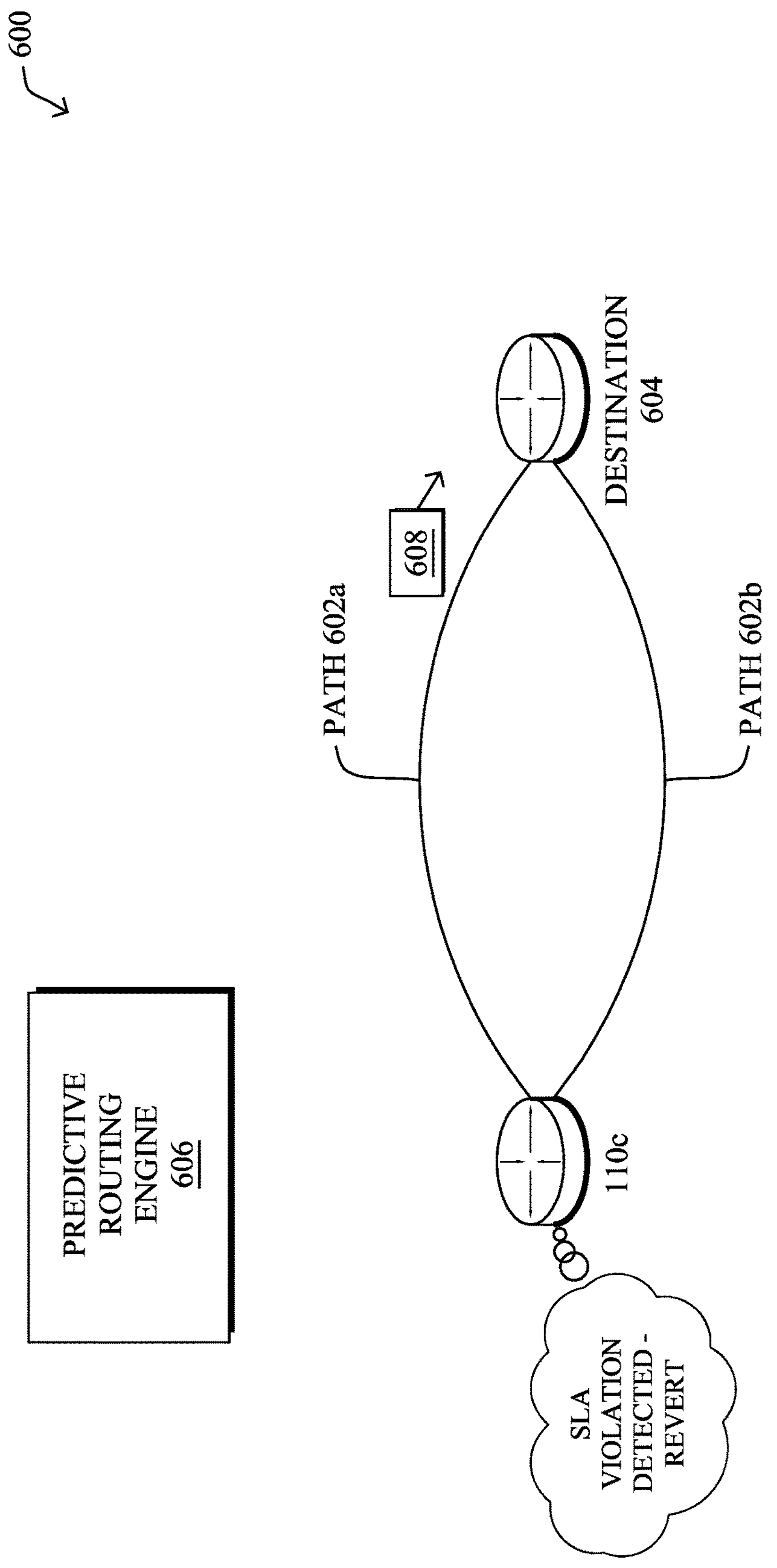
600
PREDICTIVE ROUTING ENGINE 606
608
PATH 602a
DESTINATION 604
PATH 602b
110c
SLA VIOLATION DETECTED - REVERT

FIG. 6D

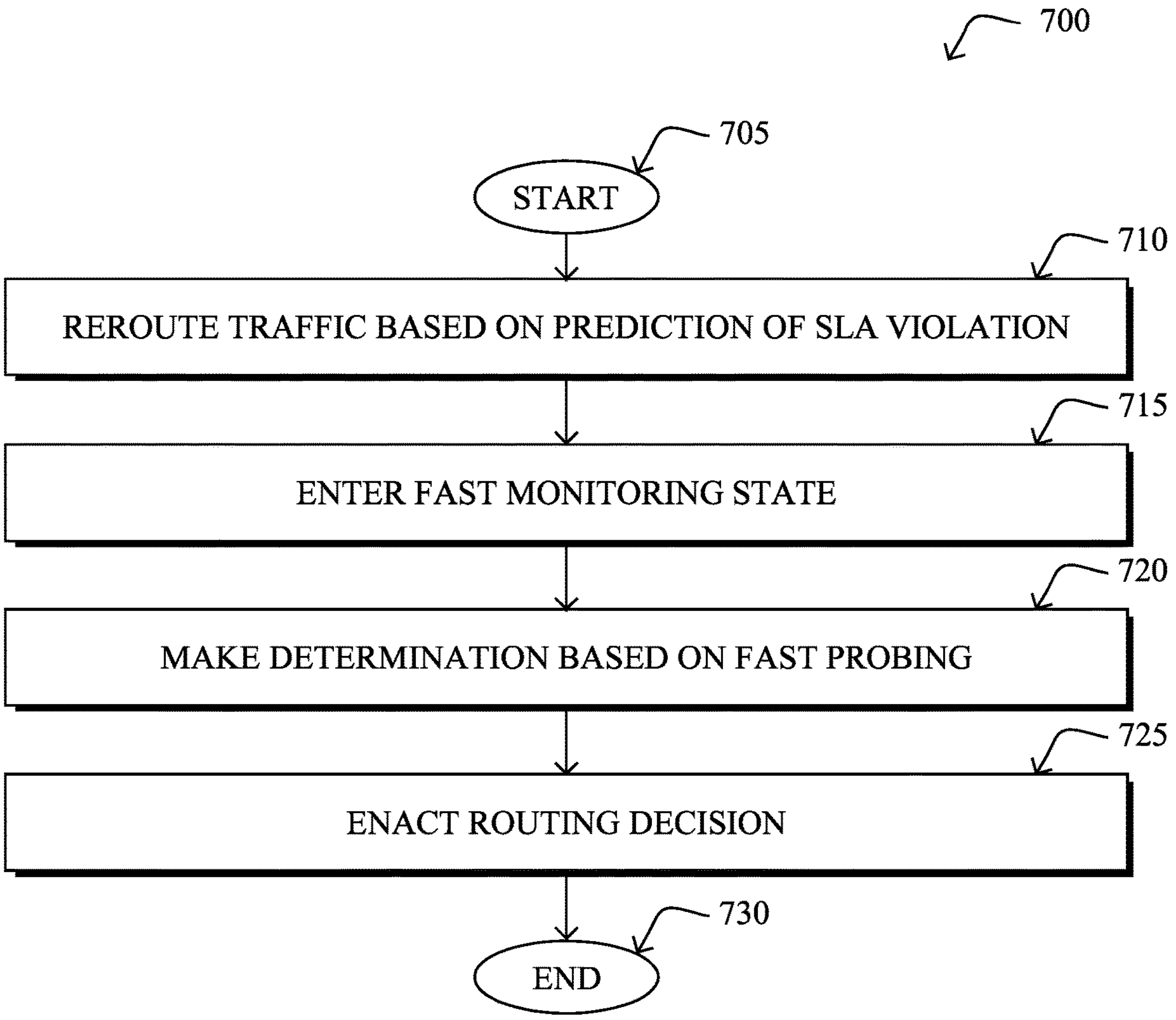
700
705
START
710
REROUTE TRAFFIC BASED ON PREDICTION OF SLA VIOLATION
715
ENTER FAST MONITORING STATE
720
MAKE DETERMINATION BASED ON FAST PROBING
725
ENACT ROUTING DECISION
730
END

FIG. 7

REVERTING ROUTING DECISIONS MADE BASED ON INCORRECT NETWORK PREDICTIONS

TECHNICAL FIELD

The present disclosure relates generally to computer networks, and, more particularly, to reverting routing decisions made based on incorrect network predictions.

BACKGROUND

Software-defined wide area networks (SD-WANs) represent the application of software-defined networking (SDN) principles to WAN connections, such as connections to cellular networks, the Internet, and Multiprotocol Label Switching (MPLS) networks. The power of SD-WAN is the ability to provide consistent service level agreement (SLA) for important application traffic transparently across various underlying tunnels of varying transport quality and allow for seamless tunnel selection based on tunnel performance characteristics that can match application SLAs.

Failure detection in a network has traditionally been reactive, meaning that the failure must first be detected before rerouting the traffic along a secondary (backup) path. In general, failure detection leverages either explicit signaling from the lower network layers or using a keep-alive mechanism that sends probes at some interval T that must be acknowledged by a receiver (e.g., a tunnel tail-end router). Typically, SD-WAN implementations leverage the keep-alive mechanisms of Bidirectional Forwarding Detection (BFD), to detect tunnel failures and to initiate rerouting the traffic onto a backup (secondary) tunnel, if such a tunnel exits. While this approach is somewhat effective at mitigating tunnel failures in an SD-WAN, reactive failure detection is also predicated on a failure first occurring. This means that traffic will be affected by the failure, until the traffic is moved to another tunnel.

With the recent evolution of machine learning, predictive failure detection in an SD-WAN now becomes possible through the use of machine learning techniques. This provides for the opportunity to implement proactive routing whereby traffic in the network is rerouted before an SLA violation occurs. However, machine learning itself is not infallible. Thus, an incorrect prediction can lead to traffic being rerouted onto another path in the network, needlessly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-**1**B illustrate an example communication network;

FIG. **2** illustrates an example network device/node;

FIGS. **3**A-**3**B illustrate example network deployments;

FIGS. **4**A-**4**B illustrate example software defined network (SDN) implementations;

FIG. **5** illustrates an example plot of path delays over time;

FIGS. **6**A-**6**D illustrate an example of a failsafe mechanism for predictive routing in a network; and

FIG. **7** illustrates an example simplified procedure to perform fast probing for a predictive routing decision.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

According to one or more embodiments of the disclosure, a networking device reroutes traffic in a network from a first

path to a second path, based on a prediction that the first path will not satisfy a service level agreement associated with the traffic. The networking device enters a fast monitoring state during which the networking device performs fast probing of the first path and of the second path onto which the traffic was rerouted. The networking device makes, based on the fast probing, a determination as to whether the first path would have violated the service level agreement and whether the second path violates the service level agreement. The networking device enacts a routing decision for the traffic by applying a routing policy to the determination.

Description

A computer network is a geographically distributed collection of nodes interconnected by communication links and segments for transporting data between end nodes, such as personal computers and workstations, or other devices, such as sensors, etc. Many types of networks are available, with the types ranging from local area networks (LANs) to wide area networks (WANs). LANs typically connect the nodes over dedicated private communications links located in the same general physical location, such as a building or campus. WANs, on the other hand, typically connect geographically dispersed nodes over long-distance communications links, such as common carrier telephone lines, optical lightpaths, synchronous optical networks (SONET), or synchronous digital hierarchy (SDH) links, or Powerline Communications (PLC) such as IEEE 61334, IEEE P1901.2, and others. The Internet is an example of a WAN that connects disparate networks throughout the world, providing global communication between nodes on various networks. The nodes typically communicate over the network by exchanging discrete frames or packets of data according to predefined protocols, such as the Transmission Control Protocol/Internet Protocol (TCP/IP). In this context, a protocol consists of a set of rules defining how the nodes interact with each other. Computer networks may be further interconnected by an intermediate network node, such as a router, to extend the effective "size" of each network.

Smart object networks, such as sensor networks, in particular, are a specific type of network having spatially distributed autonomous devices such as sensors, actuators, etc., that cooperatively monitor physical or environmental conditions at different locations, such as, e.g., energy/power consumption, resource consumption (e.g., water/gas/etc. for advanced metering infrastructure or "AMI" applications) temperature, pressure, vibration, sound, radiation, motion, pollutants, etc. Other types of smart objects include actuators, e.g., responsible for turning on/off an engine or perform any other actions. Sensor networks, a type of smart object network, are typically shared-media networks, such as wireless or PLC networks. That is, in addition to one or more sensors, each sensor device (node) in a sensor network may generally be equipped with a radio transceiver or other communication port such as PLC, a microcontroller, and an energy source, such as a battery. Often, smart object networks are considered field area networks (FANs), neighborhood area networks (NANs), personal area networks (PANs), etc. Generally, size and cost constraints on smart object nodes (e.g., sensors) result in corresponding constraints on resources such as energy, memory, computational speed and bandwidth.

FIG. **1**A is a schematic block diagram of an example computer network **100** illustratively comprising nodes/devices, such as a plurality of routers/devices interconnected by links or networks, as shown. For example, customer edge

(CE) routers **110** may be interconnected with provider edge (PE) routers **120** (e.g., PE-1, PE-2, and PE-3) in order to communicate across a core network, such as an illustrative network backbone **130**. For example, routers **110**, **120** may be interconnected by the public Internet, a multiprotocol label switching (MPLS) virtual private network (VPN), or the like. Data packets **140** (e.g., traffic/messages) may be exchanged among the nodes/devices of the computer network **100** over links using predefined network communication protocols such as the Transmission Control Protocol/Internet Protocol (TCP/IP), User Datagram Protocol (UDP), Asynchronous Transfer Mode (ATM) protocol, Frame Relay protocol, or any other suitable protocol. Those skilled in the art will understand that any number of nodes, devices, links, etc. may be used in the computer network, and that the view shown herein is for simplicity.

In some implementations, a router or a set of routers may be connected to a private network (e.g., dedicated leased lines, an optical network, etc.) or a virtual private network (VPN), such as an MPLS VPN thanks to a carrier network, via one or more links exhibiting very different network and service level agreement characteristics. For the sake of illustration, a given customer site may fall under any of the following categories:

1.) Site Type A: a site connected to the network (e.g., via a private or VPN link) using a single CE router and a single link, with potentially a backup link (e.g., a 3G/4G/5G/LTE backup connection). For example, a particular CE router **110** shown in network **100** may support a given customer site, potentially also with a backup link, such as a wireless connection.

2.) Site Type B: a site connected to the network by the CE router via two primary links (e.g., from different Service Providers), with potentially a backup link (e.g., a 3G/4G/5G/LTE connection). A site of type B may itself be of different types:

2a.) Site Type B1: a site connected to the network using two MPLS VPN links (e.g., from different Service Providers), with potentially a backup link (e.g., a 3G/4G/5G/LTE connection).

2b.) Site Type B2: a site connected to the network using one MPLS VPN link and one link connected to the public Internet, with potentially a backup link (e.g., a 3G/4G/5G/LTE connection). For example, a particular customer site may be connected to network **100** via PE-3 and via a separate Internet connection, potentially also with a wireless backup link.

2c.) Site Type B3: a site connected to the network using two links connected to the public Internet, with potentially a backup link (e.g., a 3G/4G/5G/LTE connection).

Notably, MPLS VPN links are usually tied to a committed service level agreement, whereas Internet links may either have no service level agreement at all or a loose service level agreement (e.g., a "Gold Package" Internet service connection that guarantees a certain level of performance to a customer site).

3.) Site Type C: a site of type B (e.g., types B1, B2 or B3) but with more than one CE router (e.g., a first CE router connected to one link while a second CE router is connected to the other link), and potentially a backup link (e.g., a wireless 3G/4G/5G/LTE backup link). For example, a particular customer site may include a first CE router **110** connected to PE-2 and a second CE router **110** connected to PE-3.

FIG. **1**B illustrates an example of network **100** in greater detail, according to various embodiments. As shown, network backbone **130** may provide connectivity between devices located in different geographical areas and/or different types of local networks. For example, network **100** may comprise local/branch networks **160**, **162** that include devices/nodes **10-16** and devices/nodes **18-20**, respectively, as well as a data center/cloud environment **150** that includes servers **152-154**. Notably, local networks **160-162** and data center/cloud environment **150** may be located in different geographic locations.

Servers **152-154** may include, in various embodiments, a network management server (NMS), a dynamic host configuration protocol (DHCP) server, a constrained application protocol (CoAP) server, an outage management system (OMS), an application policy infrastructure controller (APIC), an application server, etc. As would be appreciated, network **100** may include any number of local networks, data centers, cloud environments, devices/nodes, servers, etc.

In some embodiments, the techniques herein may be applied to other network topologies and configurations. For example, the techniques herein may be applied to peering points with high-speed links, data centers, etc.

According to various embodiments, a software-defined WAN (SD-WAN) may be used in network **100** to connect local network **160**, local network **162**, and data center/cloud environment **150**. In general, an SD-WAN uses a software defined networking (SDN)-based approach to instantiate tunnels on top of the physical network and control routing decisions, accordingly. For example, as noted above, one tunnel may connect router CE-2 at the edge of local network **160** to router CE-1 at the edge of data center/cloud environment **150** over an MPLS or Internet-based service provider network in backbone **130**. Similarly, a second tunnel may also connect these routers over a 4G/5G/LTE cellular service provider network. SD-WAN techniques allow the WAN functions to be virtualized, essentially forming a virtual connection between local network **160** and data center/cloud environment **150** on top of the various underlying connections. Another feature of SD-WAN is centralized management by a supervisory service that can monitor and adjust the various connections, as needed.

FIG. **2** is a schematic block diagram of an example node/device **200** that may be used with one or more embodiments described herein, e.g., as any of the computing devices shown in FIGS. **1**A-**1**B, particularly the PE routers **120**, CE routers **110**, nodes/device **10-20**, servers **152-154** (e.g., a network controller/supervisory service located in a data center, etc.), any other computing device that supports the operations of network **100** (e.g., switches, etc.), or any of the other devices referenced below. The device **200** may also be any other suitable type of device depending upon the type of network architecture in place, such as IoT nodes, etc. Device **200** comprises one or more network interfaces **210**, one or more processors **220**, and a memory **240** interconnected by a system bus **250**, and is powered by a power supply **260**.

The network interfaces **210** include the mechanical, electrical, and signaling circuitry for communicating data over physical links coupled to the network **100**. The network interfaces may be configured to transmit and/or receive data using a variety of different communication protocols. Notably, a physical network interface **210** may also be used to implement one or more virtual network interfaces, such as for virtual private network (VPN) access, known to those skilled in the art.

The memory **240** comprises a plurality of storage locations that are addressable by the processor(s) **220** and the network interfaces **210** for storing software programs and data structures associated with the embodiments described herein. The processor **220** may comprise necessary elements or logic adapted to execute the software programs and manipulate the data structures **245**. An operating system **242** (e.g., the Internetworking Operating System, or IOS®, of Cisco Systems, Inc., another operating system, etc.), portions of which are typically resident in memory **240** and executed by the processor(s), functionally organizes the node by, inter alia, invoking network operations in support of software processors and/or services executing on the device. These software processors and/or services may comprise a routing process **244** and/or a fast revert process **248**, as described herein, any of which may alternatively be located within individual network interfaces.

It will be apparent to those skilled in the art that other processor and memory types, including various computer-readable media, may be used to store and execute program instructions pertaining to the techniques described herein. Also, while the description illustrates various processes, it is expressly contemplated that various processes may be embodied as modules configured to operate in accordance with the techniques herein (e.g., according to the functionality of a similar process). Further, while processes may be shown and/or described separately, those skilled in the art will appreciate that processes may be routines or modules within other processes.

In general, routing process (services) **244** contains computer executable instructions executed by the processor **220** to perform functions provided by one or more routing protocols. These functions may, on capable devices, be configured to manage a routing/forwarding table (a data structure **245**) containing, e.g., data used to make routing/forwarding decisions. In various cases, connectivity may be discovered and known, prior to computing routes to any destination in the network, e.g., link state routing such as Open Shortest Path First (OSPF), or Intermediate-System-to-Intermediate-System (ISIS), or Optimized Link State Routing (OLSR). For instance, paths may be computed using a shortest path first (SPF) or constrained shortest path first (CSPF) approach. Conversely, neighbors may first be discovered (i.e., a priori knowledge of network topology is not known) and, in response to a needed route to a destination, send a route request into the network to determine which neighboring node may be used to reach the desired destination. Example protocols that take this approach include Ad-hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR), DYnamic MANET On-demand Routing (DYMO), etc. Notably, on devices not capable or configured to store routing entries, routing process **244** may consist solely of providing mechanisms necessary for source routing techniques. That is, for source routing, other devices in the network can tell the less capable devices exactly where to send the packets, and the less capable devices simply forward the packets as directed.

In various embodiments, as detailed further below, routing process **244** and/or fast revert process **248** may also include computer executable instructions that, when executed by processor(s) **220**, cause device **200** to perform the techniques described herein. To do so, in some embodiments, routing process **244** and/or fast revert process **248** may utilize machine learning. In general, machine learning is concerned with the design and the development of techniques that take as input empirical data (such as network statistics and performance indicators), and recognize complex patterns in these data. One very common pattern among machine learning techniques is the use of an underlying model M, whose parameters are optimized for minimizing the cost function associated to M, given the input data. For instance, in the context of classification, the model M may be a straight line that separates the data into two classes (e.g., labels) such that M=a*x+b*y+c and the cost function would be the number of misclassified points. The learning process then operates by adjusting the parameters a, b, c such that the number of misclassified points is minimal. After this optimization phase (or learning phase), the model M can be used very easily to classify new data points. Often, M is a statistical model, and the cost function is inversely proportional to the likelihood of M, given the input data.

In various embodiments, routing process **244** and/or fast revert process **248** may employ one or more supervised, unsupervised, or semi-supervised machine learning models. Generally, supervised learning entails the use of a training set of data, as noted above, that is used to train the model to apply labels to the input data. For example, the training data may include sample telemetry that has been labeled as normal or anomalous. On the other end of the spectrum are unsupervised techniques that do not require a training set of labels. Notably, while a supervised learning model may look for previously seen patterns that have been labeled as such, an unsupervised model may instead look to whether there are sudden changes or patterns in the behavior of the metrics. Semi-supervised learning models take a middle ground approach that uses a greatly reduced set of labeled training data.

Example machine learning techniques that routing process **244** and/or fast revert process **248** can employ may include, but are not limited to, nearest neighbor (NN) techniques (e.g., k-NN models, replicator NN models, etc.), statistical techniques (e.g., Bayesian networks, etc.), clustering techniques (e.g., k-means, mean-shift, etc.), neural networks (e.g., reservoir networks, artificial neural networks, etc.), support vector machines (SVMs), logistic or other regression, Markov models or chains, principal component analysis (PCA) (e.g., for linear models), singular value decomposition (SVD), multi-layer perceptron (MLP) artificial neural networks (ANNs) (e.g., for non-linear models), replicating reservoir networks (e.g., for non-linear models, typically for time series), random forest classification, or the like.

The performance of a machine learning model can be evaluated in a number of ways based on the number of true positives, false positives, true negatives, and/or false negatives of the model. For example, the false positives of the model may refer to the number of times the model incorrectly predicted that conditions in the network will result in an SLA associated with traffic for a particular application will be violated. Conversely, the false negatives of the model may refer to the number of times the model incorrectly predicted that the SLA will not be violated. True negatives and positives may refer to the number of times the model correctly predicted whether the SLA will not be violated or will be violated, respectively. Related to these measurements are the concepts of recall and precision. Generally, recall refers to the ratio of true positives to the sum of true positives and false negatives, which quantifies the sensitivity of the model. Similarly, precision refers to the ratio of true positives the sum of true and false positives.

As noted above, in software defined WANs (SD-WANs), traffic between individual sites are sent over tunnels. The tunnels are configured to use different switching fabrics, such as MPLS, Internet, 4G or 5G, etc. Often, the different switching fabrics provide different quality of service (QoS) at varied costs. For example, an MPLS fabric typically provides high QoS when compared to the Internet, but is also more expensive than traditional Internet. Some applications requiring high QoS (e.g., video conferencing, voice calls, etc.) are traditionally sent over the more costly fabrics (e.g., MPLS), while applications not needing strong guarantees are sent over cheaper fabrics, such as the Internet.

Traditionally, network policies map individual applications to Service Level Agreements (SLAs), which define the satisfactory performance metric(s) for an application, such as loss, latency, or jitter. Similarly, a tunnel is also mapped to the type of SLA that is satisfies, based on the switching fabric that it uses. During runtime, the SD-WAN edge router then maps the application traffic to an appropriate tunnel. Currently, the mapping of SLAs between applications and tunnels is performed manually by an expert, based on their experiences and/or reports on the prior performances of the applications and tunnels.

The emergence of infrastructure as a service (IaaS) and software as a service (SaaS) is having a dramatic impact of the overall Internet due to the extreme virtualization of services and shift of traffic load in many large enterprises. Consequently, a branch office or a campus can trigger massive loads on the network.

FIGS. **3**A-**3**B illustrate example network deployments **300**, **310**, respectively. As shown, a router **110** (e.g., a device **200**) located at the edge of a remote site **302** may provide connectivity between a local area network (LAN) of the remote site **302** and one or more cloud-based, SaaS providers **308**. For example, in the case of an SD-WAN, router **110** may provide connectivity to SaaS provider(s) **308** via tunnels across any number of networks **306**. This allows clients located in the LAN of remote site **302** to access cloud applications (e.g., Office 365™, Dropbox™, etc.) served by SaaS provider(s) **308**.

As would be appreciated, SD-WANs allow for the use of a variety of different pathways between an edge device and an SaaS provider. For example, as shown in example network deployment **300** in FIG. **3**A, router **110** may utilize two Direct Internet Access (DIA) connections to connect with SaaS provider(s) **308**. More specifically, a first interface of router **110** (e.g., a network interface **210**, described previously), Int 1, may establish a first communication path (e.g., a tunnel) with SaaS provider(s) **308** via a first Internet Service Provider (ISP) **306***a*, denoted ISP 1 in FIG. **3**A. Likewise, a second interface of router **110**, Int 2, may establish a backhaul path with SaaS provider(s) **308** via a second ISP **306***b*, denoted ISP 2 in FIG. **3**A.

FIG. **3**B illustrates another example network deployment **310** in which Int 1 of router **110** at the edge of remote site **302** establishes a first path to SaaS provider(s) **308** via ISP 1 and Int 2 establishes a second path to SaaS provider(s) **308** via a second ISP **306***b*. In contrast to the example in FIG. **3**A, Int 3 of router **110** may establish a third path to SaaS provider(s) **308** via a private corporate network **306***c* (e.g., an MPLS network) to a private data center or regional hub **304** which, in turn, provides connectivity to SaaS provider(s) **308** via another network, such as a third ISP **306***d*.

Regardless of the specific connectivity configuration for the network, a variety of access technologies may be used (e.g., ADSL, 4G, 5G, etc.) in all cases, as well as various networking technologies (e.g., public Internet, MPLS (with or without strict SLA), etc.) to connect the LAN of remote site **302** to SaaS provider(s) **308**. Other deployments scenarios are also possible, such as using Colo, accessing SaaS provider(s) **308** via Zscaler or Umbrella services, and the like.

FIG. **4**A illustrates an example SDN implementation **400**, according to various embodiments. As shown, there may be a LAN core **402** at a particular location, such as remote site **302** shown previously in FIGS. **3**A-**3**B. Connected to LAN core **402** may be one or more routers that form an SD-WAN service point **406** which provides connectivity between LAN core **402** and SD-WAN fabric **404**. For instance, SD-WAN service point **406** may comprise routers **110***a*-**110***b*.

Overseeing the operations of routers **110***a*-**110***b* in SD-WAN service point **406** and SD-WAN fabric **404** may be an SDN controller **408**. In general, SDN controller **408** may comprise one or more devices (e.g., devices **200**) configured to provide a supervisory service, typically hosted in the cloud, to SD-WAN service point **406** and SD-WAN fabric **404**. For instance, SDN controller **408** may be responsible for monitoring the operations thereof, promulgating policies (e.g., security policies, etc.), installing or adjusting IPsec routes/tunnels between LAN core **402** and remote destinations such as regional hub **304** and/or SaaS provider(s) **308** in FIGS. **3**A-**3**B, and the like.

As noted above, a primary networking goal may be to design and optimize the network to satisfy the requirements of the applications that it supports. So far, though, the two worlds of "applications" and "networking" have been fairly siloed. More specifically, the network is usually designed in order to provide the best SLA in terms of performance and reliability, often supporting a variety of Class of Service (CoS), but unfortunately without a deep understanding of the actual application requirements. On the application side, the networking requirements are often poorly understood even for very common applications such as voice and video for which a variety of metrics have been developed over the past two decades, with the hope of accurately representing the Quality of Experience (QoE) from the standpoint of the users of the application.

More and more applications are moving to the cloud and many do so by leveraging an SaaS model. Consequently, the number of applications that became network-centric has grown approximately exponentially with the raise of SaaS applications, such as Office 365, ServiceNow, SAP, voice, and video, to mention a few. All of these applications rely heavily on private networks and the Internet, bringing their own level of dynamicity with adaptive and fast changing workloads. On the network side, SD-WAN provides a high degree of flexibility allowing for efficient configuration management using SDN controllers with the ability to benefit from a plethora of transport access (e.g., MPLS, Internet with supporting multiple CoS, LTE, satellite links, etc.), multiple classes of service and policies to reach private and public networks via multi-cloud SaaS.

Application aware routing usually refers to the ability to rout traffic so as to satisfy the requirements of the application, as opposed to exclusively relying on the (constrained) shortest path to reach a destination IP address. Various attempts have been made to extend the notion of routing, CSPF, link state routing protocols (ISIS, OSPF, etc.) using various metrics (e.g., Multi-topology Routing) where each metric would reflect a different path attribute (e.g., delay, loss, latency, etc.), but each time with a static; metric. At best, current approaches rely on SLA templates specifying the application requirements so as for a given path (e.g., a tunnel) to be "eligible" to carry traffic for the application. In turn, application SLAs are checked using regular probing. Other solutions compute a metric reflecting a particular network characteristic (e.g., delay, throughput, etc.) and then selecting the supposed 'best path,' according to the metric.

The term 'SLA failure' refers to a situation in which the SLA for a given application, often expressed as a function of delay, loss, or jitter, is not satisfied by the current network path for the traffic of a given application. This leads to poor QoE from the standpoint of the users of the application. Modern SaaS solutions like Viptela, CloudonRamp SaaS, and the like, allow for the computation of per application QoE by sending HyperText Transfer Protocol (HTTP) probes along various paths from a branch office and then route the application's traffic along a path having the best QoE for the application. At a first sight, such an approach may solve many problems. Unfortunately, though, there are several shortcomings to this approach:

- The SLA for the application is 'guessed,' using static thresholds.
- Routing s still entirely reactive: decisions are made using probes that reflect the status of a path at a given time, in contrast with the notion of an informed decision.
- SLA failures are in the Internet and a good proportion of them could be avoided (using an alternate path), if predicted in advance.

In various embodiments, the techniques herein allow for a predictive application aware routing engine to be deployed, such as in the cloud, to control routing decisions in a network. For instance, the predictive application aware routing engine may be implemented as part of an SDN controller (e.g., SDN controller **408**) or other supervisory service, or may operate in conjunction therewith. For instance, FIG. 4B illustrates an example **410** in which SDN controller **408** includes a predictive application aware routing engine **412** (e.g., through execution of routing process **244** and/or fast revert process **248**). Further embodiments provide for predictive application aware routing engine **412** to be hosted on a router **110** or at any other location in the network.

During execution, predictive application aware routing engine **412** makes use of a high volume of network and application telemetry (e.g., from routers **110***a*-**110***b*, SD-WAN fabric **404**, etc.) so as to compute statistical and/or machine learning models to control the network with the objective of optimizing the application experience and reducing potential down times. To that end, predictive application aware routing engine **412** may compute a variety of models to understand application requirements, and predictably route traffic over private networks and/or the Internet, thus optimizing the application experience while drastically reducing SLA failures and downtimes.

In other words, predictive application aware routing engine **412** may first predict SLA violations in the network that could affect the QoE of an application (e.g., due to spikes of packet loss or delay, sudden decreases in bandwidth, etc.). In turn, predictive application aware routing engine **412** may then implement a corrective measure, such as rerouting the traffic of the application, prior to the predicted SLA violation. For instance, in the case of video applications, it now becomes possible to maximize throughput at any given time, which is of utmost importance to maximize the QoE of the video application. Optimized throughput can then be used as a service triggering the routing decision for specific application requiring highest throughput, in one embodiment.

By way of example, FIG. **5** illustrates a plot **500** of timeseries of delay observed by an edge device to reach a given destination via both the Internet (e.g., via a DIA connection) and a private data center (e.g., via traffic backhauling). Typically, the DIA connection provides the shortest delays to the destination. However, there are also times

504*a*-**504***c* during which the backhauled connection via the private data center outperforms the DIA connection. Indeed, during times **504***a*-**504***c*, the DIA connection exhibits spikes of delay, such that SLA **502** is violated.

As noted above, an application aware predictive routing engine may identify trend changes in the network KPIs of a path by utilizing several probes that measure path health (e.g., loss, latency and jitter). In turn, the predictive routing engine utilizes statistical and/or machine learning techniques to predict such path deterioration in the future (e.g., predict SLA violations) and generate routing "patches" (e.g., policies) that proactively reroute application traffic before an SLA violation occurs.

One of the main challenges of predictive routing is in the ability to accurately perform predictions of SLA violations. Generally speaking, the SLA violation predictions should be made with high recall, for the solution to be effective. However, recall is not the only consideration. Indeed, in some instances, it might also be acceptable not to predict an SLA violation and fall back to a reactive routing approach whereby SLAs are checked thanks to probing and the traffic is rerouted only when an actual SLA violation is detected.

Precision represents another performance metric for the SLA violation predictions, which can be particularly critical in situations in which the number of total positive examples is low (e.g., are rare events). Indeed, even a small number of false positives can strongly affect the precision, when the number of true positives is low. Furthermore, the traffic may be unnecessarily rerouted onto a path that may eventually not meet the SLA. In some embodiments, this can be mitigated against by also forecasting whether the new path will violate the SLA. However, rerouting traffic onto the new path will unavoidably change the conditions, including ways that could cause the SLA to be violated. This can be doubly problematic in situations in which the original path does not exhibit the predicted SLA violation, meaning that the predictive reroute actually made things worse.

Reverting Routing Decisions

The techniques introduced herein allow for the fast reversion of rerouting decisions on detection of a predictive routing engine incorrectly predicting an SLA violation on the primary/original path and/or traffic being rerouted onto a secondary/new path that results in a violation of the SLA. In some aspects, the techniques herein allow for a router to locally perform fast monitoring, so as to actively monitor the states of both path using various timing strategies. Then, on detection of an incorrect prediction or SLA violation on the secondary path, the rerouting decision can be quickly reverted, either by canceling the rerouting or performing another mitigation action, such as load balancing the traffic.

Illustratively, the techniques described herein may be performed by hardware, software, and/or firmware, such as in accordance with the fast revert process **248**, which may include computer executable instructions executed by the processor **220** (or independent processor of interfaces **210**) to perform functions relating to the techniques described herein (e.g., in conjunction with routing process **244**).

Specifically, according to various embodiments, a networking device reroutes traffic in a network from a first path to a second path, based on a prediction that the first path will not satisfy a service level agreement associated with the traffic. The networking device enters a fast monitoring state during which the networking device performs fast probing of the first path and of the second path onto which the traffic was rerouted. The networking device makes, based on the fast probing, a determination as to whether the first path would have violated the service level agreement and whether the second path violates the service level agreement. The networking device enacts a routing decision for the traffic by applying a routing policy to the determination.

As pointed out previously, incorrectly predicting an SLA violation by a primary path can lead to its traffic being proactively rerouted onto a secondary path. If the predicted SLA violation was a false positive, this means that the traffic was rerouted without reason. Worse, rerouting is always a costly operation, from the back-head perspective. Furthermore, rerouting may disrupt some flows because of packet re-ordering and unavoidable increase of jitter. However, the false positive can have even worse effects, if the secondary path onto which the traffic is rerouted does not meet the SLA of the traffic.

Operationally, FIGS. **6A**-**6D** illustrate the operation of a failsafe mechanism for predictive routing, according to various embodiments. As shown, assume that a network **600** includes a router **110***c* that is to send application traffic **608** to a destination **604**, such as an SaaS provider or the like. To do so, there may be two or more possible routing paths between router **110***c* and destination **604**. For instance, router **110***c* may be able to route application traffic **608** via one or more DIA connections, MPLS backhaul connections, or the like. For simplicity, two paths, path **602***a* and path **602***b* are shown.

In addition, there may also be a predictive routing engine **606** that uses telemetry data collected from network **600** to predict SLA violations along path **602***a* and path **602***b* and push routing patches to router **110***c* that cause router **110***c* to proactively avoid such violations by rerouting its traffic onto another path. For instance, as shown, assume that router **110***c* routes application traffic **608** via path **602***a*, which acts as the primary path for application traffic **608**. Now, assume that predictive routing engine **606** predicts that path **602***a* will violate the SLA of application traffic **608**. In such a case, application traffic **608** may generate and send a routing patch **610**, so as to reroute application traffic **608** onto path **602***b* in advance of the predicted SLA violation by path **602***a*.

In FIG. **6**B, after receiving routing patch **610**, router **110***c* may reroute application traffic **608** onto the secondary path, path **602***b*, to avoid the predicted SLA violation by path **602***a*. According to various embodiments, router **110***c* may also enter into a Fast-Monitoring (FM) mode either before, shortly after, or concurrently with the rerouting of application traffic **608** onto path **602***b* at time according to routing patch **610** from predictive routing engine **606**.

While in FM mode, router **110***c* may begin a fast probing cycle onto path **602***a* and path **602***b* whereby probes **612***a* and probes **612***b*, respectively, are sent. Such probes **612***a*-**612***b* may be of different forms, depending on the natures of paths **602***a*-**602***b*. For instance, probes **612***a*-**612***b* may take the form of BFD probes on SD-WAN tunnels, HTTP probes for CloudOnRamp, etc. During this, router **110***c* may send probes **602***a*-**602***b* every X-number of seconds where X<Y (Y being the default mode). In other words, router **110***c* may send probes along paths **602***a*-**602***b* at a higher frequency while in FM mode than normally. In various embodiments, X could be computed taking into account the link speed, level of congestion, level of CPU usage, or other performance metrics for router **110***c*.

Based on the results of probing path **602***a*, router **110***c* may then perform local computations to check the SLA along path **602***a*. To this end, in some embodiments, predictive routing engine **606** may employ a custom extension to routing patch **610** that specifies the SLA template related

to its rerouting prediction regarding path **602***a* (e.g., max delay, max loss, max jitter, etc.).

In a first embodiment, router **110***c* may switch application traffic **608** onto path **602***b*. However, in a further embodiment, router **110***c* may also send a local shadow copy of the packets of application traffic **608** as traffic copy **608***a* onto path **602***a* with a flag indicating to destination **604** or the tail-end of the tunnel that it should be dropped on reception. The aim of sending such a copy of application traffic **608** is to check whether the SLA would have been violated had the traffic stayed on path **602***a*, thus confirming whether the predicted SLA violation was a true positive or was incorrect (i.e., a false positive). Optionally, router **110***c* may send traffic copy **608***a* along path **602***a* for a shorter period of time, which may be configurable. In addition, router **110***c* may recolor as traffic copy **608***a*, to assign a lower priority to it, should other non-rerouted traffic still be sent along path **602***a*, to avoid QoS degradation of that traffic.

Router **110***c* may also perform fast probing of path **602***b*, potentially with a different probing interval X' than that of path **602***a*. In turn, router **110***c* may make local computations at a higher pace, to assess whether path **602***b* violates the SLA associated with application traffic **608**. Optimally, a different statistical moment may also be used while router **110***c* is in FM mode. For instance, during normal operations, router **110***c* may usually check SLA violations during averages over ten-minute time periods. However, during FM mode, router **110***c* may check the SLA for violations at a much higher pace, such as every thirty seconds, using Max or higher percentile values.

In other embodiments, router **110***c* may monitor different application experience metrics, while in FM mode, in addition to any SLA violations. For example, router **110***c* may monitor the number of users affected by an SLA violation, the number of session disruptions, or even explicit application feedback information (e.g., degradation of video application traffic can be detected by changes in the resolution observed over paths).

As shown in FIG. **6**C, router **110***c* may send a report **612** to predictive routing engine **606** indicative of the results of its FM mode, according to various embodiments. For instance, report **612** may indicate whether the SLA was met or violated by path **602***a* or path **602***b*, whether a copy of traffic **608** was sent on path **602***a*, additional information related to the link status, queue status, application experience metrics, or the like. Predictive routing engine **606** may then use the information from report **612** in further predictions.

If the SLA of application traffic **608** was violated by path **602***a*, but not by path **602***b*, this is the ideal situation, meaning that predictive routing engine **606** correctly predicted that path **602***a* would violate the SLA of application traffic **608** and was able to trigger a reroute of traffic **608** onto path **602***b*, proactively. Conversely, if the SLA was not violated by either of paths **602***a*-**602***b*, then application traffic **608** was unnecessarily rerouted but with (almost) no consequences. Finally, if the SLA was violated after rerouting application traffic **608** onto path **602***b*, but no such SLA violation would have occurred on path **602***a*, not only did predictive routing engine **606** make a wrong prediction (e.g., a false positive), but the decision to reroute application traffic **608** was also incorrect. Finally, if the SLA is violated on both paths **602***a*-**602***b*, thanks to additional information obtained by router **110***c* from fast probing, predictive routing engine **606** may be able to determine whether the rerouting decision was still beneficial to application traffic **608** by comparing the SLA on path **602***a* and path **602***b*, especially in presence of traffic copy **608***a* on path **602***a*.

Another aspect of the techniques herein is a fast revertive mechanism, according to various embodiments. During its FM phase, which may be dynamic, router **110***c* may perform regular checks of the SLA with respect to paths **602***a*-**602***b* at a regular time interval I. In turn, router **110***c* may enforce a revertive policy, based on the results of the checks. Such policies may be sent to router **110***c* by predictive routing engine **606** or another source, or configured directly on router **110***c*. For instance, the possible revertive policies may include any or all of the following:

- SLA violated on path **602***a* and not on path **602***b*: Do nothing.
- SLA violated on path **602***b* and not on path **602***a*: In this case, router **110***c*, if allowed, may trigger a revertive mode where the original application traffic **608** is switched back from path **602***b* to path **602***a*. In turn, router **110***c* may also notify predictive routing engine **606** of this revertive decision (e.g., via report **612** or another notification).
- SLA not violated on path **602***a* or path **602***b*: Do nothing.
- SLA violated on both path **602***a* and on path **602***b*: In this situation, router **110***c* may be allowed to perform load balancing on the rerouted application traffic **608** onto path **602***a* and path **602***b*, according to an approach governed by predictive routing engine **606** or locally configured on router **110***c*. In this case, router **110***c* may report its decision to predictive routing engine **606** (e.g., via report **612** or another notification). In addition, router **110***c* may continue to monitor the situation and send additional reports to predictive routing engine **606**, along with optional parameters (e.g., Netflow parameters, queue statistics, etc.). Such information may further be used by predictive routing engine **606** to improve its predictions. In another embodiment, a further strategy may be to load balance application traffic **608** onto path **602***a* and path **602***b*, according to its traffic priority.

For instance, as shown in FIG. **6**D, assume that the SLA was violated on path **602***b*, but not on path **602***a*. In such a case, router **110***c* may revert the reroute of predictive routing engine **606** from path **602***b* back onto path **602***a*.

In yet another embodiment, router **110***c* may be allowed to perform additional trials. Under this, even if application traffic **608** is switched back to the primary path, path **602***a*, router **110***c* may continue to record local conditions and may make a second rerouting attempt to move application traffic **608** back onto path **602***b*, if the total rerouting period has not yet expired. For example, assume that router **110***c* determines that the link utilization suddenly decreases or had suddenly increased, prior to time T_1 (e.g., when the SLA violation was predicted to occur). That may be due, for instance, to unexpected traffic being sent via path **602***b*, prior to the rerouting of application traffic **608**. In such a case, router **110***c* may make a second attempt to reroute application traffic **608** onto path **602***b* and report the results of this to predictive routing engine **606**. Optionally, router **110***c* may perform a set of N-number attempts for the reroute, each attempt being evenly spread out in time or, alternatively, separated by increasing periods of time (e.g., using dampening).

In yet another embodiment, the data from the N-number of rerouting attempts by router **110***c* may be analyzed statistically, to check whether rerouting onto path **602***b* is in fact significantly better than path **602***a* in terms of SLA violation. For example, router **110***c* may record the fraction of time the SLA is violated on path **602***a* and on path **602***b* for the N-number of attempts. Then, a statistical hypothesis test, such as Two sample Kolmogorov-Smirnov (KS)-Test, can be performed to check whether the above conditions can be inferred (e.g., SLA violated on path **602***a*, and not on path **602***b*).

Note that traditional routing approaches such as ISIS, OSPF, etc., or even MPLS TE Fast Reroute where tunnel head-ends are rerouted onto the primary path upon global re-optimization, lack any form of revertive operation.

In further embodiments, predictive routing engine **606** may use any reports of false positives by router **110***c* to improve the prediction accuracy of its model. Optionally, a report of a false positive by router **110***c* may even trigger model retraining.

In addition, the false positive rate can also be used to adjust the revertive mode described previously. For instance, if the false positive rate increases, predictive routing engine **606** may adjust the FM period of router **110***c*, such as by using a shorter interval between probing or a shorter period of time I to decide whether to revert. Conversely, if the false positive rate decreases, meaning that the performance of the prediction model actually increased, predictive routing engine **606** may opt to increase either or both of these periods of time on router **110***c*. Similarly, predictive routing engine **606** may use metrics such as the rate of SLA violations on path **602b** and not on path **602***a*, to adapt the policy and potentially reduce the ability of the system for the automation of rerouting. Indeed, if the predictions by predictive routing engine **606** are incorrect and traffic is rerouted onto a secondary path resulting in an SLA violation, it may be desirable to restrict the ability for the system to perform close loop control, in some embodiments. Note also that the additional information provided by router **110***c* on the status along path **602***b* when rerouting application traffic **608** may be used by predictive routing engine **606** its choice of alternate path for further rerouting decisions, when it forecasts SLA violations along the primary path **602***a* (e.g., by opting to reroute further traffic along a third path instead of path **602***b*, etc.).

FIG. **7** illustrates an example simplified procedure to perform fast probing for a predictive routing decision, in accordance with one or more embodiments described herein. For example, a non-generic, specifically configured device (e.g., device **200**), such as a networking device (e.g., a router, an SDN controller for an SD-WAN, etc.), may perform procedure **700** by executing stored instructions (e.g., process **248**). The procedure **700** may start at step **705**, and continues to step **710**, where, as described in greater detail above, the networking device may reroute traffic in a network from a first path to a second path, based on a prediction that the first path will not satisfy a SLA associated with the traffic. For instance, a machine learning-based predictive routing engine, either locally on the networking device or remote to it, may make the prediction.

At step **715**, as detailed above, the networking device may enter a fast monitoring state during which the networking device performs fast probing of the first path and of the second path onto which the traffic was rerouted, as described in greater detail above. In general, the fast probing may comprise sending probes along the first path and along the second path at a faster rate than a default probing rate used by the networking device. For instance, the networking device may send BFD probes, HTTP probes, or the like, along the first and second paths, to assess their performance metrics. In yet another embodiment, the fast probing may comprise sending a copy of the traffic along the first path with a flag indicating that the copy of the traffic should be dropped upon reception.

At step **720**, the networking device may make, based on the fast probing, a determination as to whether the first path would have violated the SLA and whether the second path violates the SLA, as described in greater detail above. In one embodiment, the determination indicates that the first path would not have violated the SLA and that the second path does violate the SLA. In another embodiment, the determination indicates that the first path would have violated the SLA and that the second path does not violate the SLA. In a further embodiment, the determination indicates that the first path would have violated the SLA and that the second path does violate the SLA.

At step **725**, as detailed above, the networking device may enact a routing decision for the traffic by applying a routing policy to the determination. In one embodiment, the device may do so by rerouting the traffic back onto the first path, as in the case where the determination indicates that the first path would not have violated the SLA and that the second path does violate the SLA. In such cases, the networking device may notify a machine learning-based predictive routing engine that made the prediction that the first path will not satisfy the SLA, of the determination, to improve prediction accuracy of the machine learning-based predictive routing engine. In further embodiments, the networking device may also perform a second attempt to reroute the traffic onto the second path, so as to perform an additional trial of the second path. the In another embodiment, the device may enact the routing decision by keeping the traffic on the second path, as in the case in which the determination indicates that the first path would have violated the SLA and that the second path does not violate the service level agreement. In yet another embodiment, the networking device may enact the routing decision by load balancing the traffic between the first path and the second path, as in the case in which the determination indicates that the first path would have violated the service level agreement and that the second path does violate the service level agreement. Procedure **700** then ends at step **730**.

It should be noted that while certain steps within procedure **700** may be optional as described above, the steps shown in FIG. **7** are merely examples for illustration, and certain other steps may be included or excluded as desired. Further, while a particular order of the steps is shown, this ordering is merely illustrative, and any suitable arrangement of the steps may be utilized without departing from the scope of the embodiments herein.

The techniques described herein, therefore, introduce a safeguard mechanism for predictive routing deployments in a network. By fast probing network paths involved in a predictive routing decision, corrective measure can be taken quickly, to mitigate any harm caused by false positives. In further aspects, a feedback loop with the predictive routing engine can also be used, to help improve the prediction accuracy of it over time.

While there have been shown and described illustrative embodiments that provide for reverting routing decisions made based on incorrect network predictions, it is to be understood that various other adaptations and modifications may be made within the spirit and scope of the embodiments herein. For example, while certain embodiments are described herein with respect to using certain models for purposes of predicting tunnel failures, SLA violations, or the like, the models are not limited as such and may be used for other types of predictions, in other embodiments. In addition, while certain protocols are shown, other suitable protocols may be used, accordingly.

The foregoing description has been directed to specific embodiments. It will be apparent, however, that other variations and modifications may be made to the described embodiments, with the attainment of some or all of their advantages. For instance, it is expressly contemplated that the components and/or elements described herein can be implemented as software being stored on a tangible (non-transitory) computer-readable medium (e.g., disks/CDs/RAM/EEPROM/etc.) having program instructions executing on a computer, hardware, firmware, or a combination thereof. Accordingly, this description is to be taken only by way of example and not to otherwise limit the scope of the embodiments herein. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the embodiments herein.

The invention claimed is:

1. A method comprising:

rerouting, by a networking device, traffic in a network from a first path to a second path, based on a prediction that the first path will not satisfy a service level agreement associated with the traffic;

entering, by the networking device, a fast monitoring state during which the networking device performs fast probing of the first path and of the second path onto which the traffic was rerouted;

making, by the networking device and based on the fast probing, a determination as to whether the first path would have violated the service level agreement and whether the second path violates the service level agreement; and

enacting, by the networking device, a routing decision for the traffic by applying a routing policy to the determination.

2. The method as in claim **1**, wherein the network comprises a software-defined wide area network (SD-WAN) and wherein the first path and the second path comprise network tunnels.

3. The method as in claim **1**, wherein the fast probing comprises sending probes along the first path and along the second path at a faster rate than a default probing rate used by the networking device.

4. The method as in claim **1**, wherein performing fast probing of the first path and of the second path comprises send Bidirectional Forwarding Detection (BFD) probes or Hypertext Transfer Protocol (HTTP) probes.

5. The method as in claim **1**, wherein the determination indicates that the first path would not have violated the service level agreement and that the second path does violate the service level agreement, and wherein enacting the routing decision comprises:

rerouting the traffic back onto the first path.

6. The method as in claim **5**, further comprising:

notifying a machine learning-based predictive routing engine that made the prediction that the first path will not satisfy the service level agreement of the determination, to improve prediction accuracy of the machine learning-based predictive routing engine.

7. The method as in claim **5**, further comprising:

performing a second attempt to reroute the traffic onto the second path.

8. The method as in claim **1**, wherein the determination indicates that the first path would have violated the service level agreement and that the second path does not violate the service level agreement, and wherein enacting the routing decision comprises:

keeping the traffic on the second path.

9. The method as in claim **1**, wherein the determination indicates that the first path would have violated the service level agreement and that the second path does violate the service level agreement, and wherein enacting the routing decision comprises:

load balancing the traffic between the first path and the second path.

10. The method as in claim **1**, wherein the fast probing comprises sending a copy of the traffic along the first path with a flag indicating that the copy of the traffic should be dropped upon reception.

11. An apparatus, comprising:

one or more network interfaces;

a processor coupled to the one or more network interfaces and configured to execute one or more processes; and

a memory configured to store a process that is executable by the processor, the process when executed configured to:

reroute traffic in a network from a first path to a second path, based on a prediction that the first path will not satisfy a service level agreement associated with the traffic;

enter a fast monitoring state during which the apparatus performs fast probing of the first path and of the second path onto which the traffic was rerouted;

make, based on the fast probing, a determination as to whether the first path would have violated the service level agreement and whether the second path violates the service level agreement; and

enact a routing decision for the traffic by applying a routing policy to the determination.

12. The apparatus as in claim **11**, wherein the network comprises a software-defined wide area network (SD-WAN) and wherein the first path and the second path comprise network tunnels.

13. The apparatus as in claim **11**, wherein the fast probing comprises sending probes along the first path and along the second path at a faster rate than a default probing rate used by the apparatus.

14. The apparatus as in claim **11**, wherein performing fast probing of the first path and of the second path comprises send Bidirectional Forwarding Detection (BFD) probes or Hypertext Transfer Protocol (HTTP) probes.

15. The apparatus as in claim **11**, wherein the determination indicates that the first path would not have violated the service level agreement and that the second path does violate the service level agreement, and wherein the apparatus enacts the routing decision by rerouting the traffic back onto the first path.

16. The apparatus as in claim **15**, wherein the process when executed is further configured to:

notify a machine learning-based predictive routing engine that made the prediction that the first path will not satisfy the service level agreement of the determination, to improve prediction accuracy of the machine learning-based predictive routing engine.

17. The apparatus as in claim **15**, wherein the process when executed is further configured to:

perform a second attempt to reroute the traffic onto the second path.

18. The apparatus as in claim **11**, wherein the determination indicates that the first path would have violated the service level agreement and that the second path does not violate the service level agreement, and wherein the apparatus enacts the routing decision by keeping the traffic on the second path.

19. The apparatus as in claim **11**, wherein the determination indicates that the first path would have violated the service level agreement and that the second path does violate the service level agreement, and wherein enacting the routing decision by load balancing the traffic between the first path and the second path.

20. A tangible, non-transitory, computer-readable medium storing program instructions that cause a networking device to execute a process comprising:

rerouting, by the networking device, traffic in a network from a first path to a second path, based on a prediction that the first path will not satisfy a service level agreement associated with the traffic;

entering, by the networking device, a fast monitoring state during which the networking device performs fast probing of the first path and of the second path onto which the traffic was rerouted;

making, by the networking device and based on the fast probing, a determination as to whether the first path would have violated the service level agreement and whether the second path violates the service level agreement; and

enacting, by the networking device, a routing decision for the traffic by applying a routing policy to the determination.

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